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GENERAL DESIGN OF THE EAST DELAWARE WATER SUPPLY TUNNEL

by Stanley M. Dore, M. ASCE

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STRUCTURAL ENGINEERING DIVISION

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GENERAL DESIGN FEATURES OF THE EAST DELAWARE WATER SUPPLY TUNNEL

Stanley M. Dore

The East Delaware Tunnel, located in Delaware and Sullivan Counties of the State of New York, is a water supply tunnel being built by the Board of Water Supply of the City of New York to carry the waters to be stored in the Pepacton Reservoir to the Rondout Reservoir, from which reservoir these waters will be available through the Delaware Aqueduct system for consumption by the water users in New York City. No attempt is made in this paper to describe the general features of the New York water supply system. Information and description of this system may be obtained by reference to many previous papers, particularly to the broad and comprehensive one delivered before the Municipal Engineers of the City of New York on April 25, 1951 by Irving V. A. Huie, President of the Board of Water Supply.

The Pepacton Reservoir, construction of which is nearing completion, is a collection reservoir, storing flood flows from a drainage area of 372 square miles, and when in full operation will increase the available sources of the City by an amount on the average of 335 m.g.d. Drafts from this reservoir will be made through the East Delaware Tunnel, so named because it will carry storage developed by the Pepacton Reservoir of waters flowing in the East Branch of the Delaware River even though such aqueduct connects to the Delaware Aqueduct system from the west. The East Delaware Tunnel was driven through solid rock for a distance of about 25 miles and for a finished inside diameter of 11' - 4", and was lined with concrete, the thickness of which depended upon whether or not the roof required no support or the heaviest type of support. The tunnel bore varied for the unsupported sections from a required minimum of 11 inches of lining to about 19 inches, and for the supported section, the same minimum applied if it could be attained, the thickness of lining was greater than 19 inches as needed to accomodate the supporting members. On the average, however, the lining will be about 19 inches, or more, in thickness.

Interesting construction features involved in the building of this tunnel will be described in a companion paper, and this present paper will be limited to discussion of the general design features of the relatively long and large rock tunnel and its appurtenances.

To determine the location of the tunnel, geological surveys and investigations, including the sinking of about 50 bore holes to investigate the location of the underlying rock formations and their characteristics, revealed that sufficient rock cover was available for a pressure tunnel and that the rock characteristics were such that no uneconomical features, such as undue water, faults or grossly unsatisfactory rock materials, were likely to be encountered. The rock formations consist of fine grained grey and red sandstones and shales, generally of rather hard and solid characteristics, but bedded and stratified generally in rather thin layers and in such manner as to require support of some nature generally throughout its length, in the interests of

safety while driving and concreting. Figure 3 shows a typical cross-section for the supported section as indicated by the contract drawings and Figure 7 shows the roof of the supported section as constructed both in accordance with the indicated design and also in accordance with the roof bolting type of support largely used in place of the former type. A study of the profile will reveal that the tunnel is driven generally through hills and mountains existing between the two watersheds and well below the intervening valleys.

In profile, the tunnel is located with alternating sloping and level stretches so arranged that, except for the heading from the intake portal which has a downgrade of 0.15 per cent, all headings would be driven with level or upgrades. The maximum grade is 0.50 per cent. The tunnel invert at the intake chamber is Elevation 1143.0 above mean sea level at Sandy Hook, the base used by the United States Geological Survey, the Board of Water Supply and others, and at the Rondout Reservoir at about Elevation 840.0, the flow line of this reservoir. The minimum draft level for the Pepacton Reservoir was fixed at Elevation 1150, and the tunnel was located sufficiently below that elevation to permit a flow approximately equal to the safe yield under all conditions. Such profile location was found to be sufficiently deep, even at the stream crossings, to give a rock cover adequate to over-balance the outward hydraulic pressures which occur with a full reservoir at Pepacton and no flow in the tunnel, the control gates at the downstream end being closed. At the outlet end, however, where the rock cover diminishes near the portal, the last 520 feet requires a steel interlining.

The original layout of this tunnel anticipated driving from two portals and five construction shafts; but, as such a program entailed deep shafts with sites in isolated locations, a study was made of reducing the number of shafts. This study indicated, after careful consideration of the long distances between shaft sites and all the factors involved, that a tunnel driven from the portals and two shafts would be about one and one-half million dollars cheaper than the original layout with five shafts. Such economy was estimated in spite of disadvantages in driving by the long headings involved, because the construction costs of the extra shafts, including power plants or long transmission lines and access roads to the shaft locations, were substantial. In addition, the feasibility of long headings has been previously demonstrated in recent years in the far west, the Continental Divide (Adams), Carlton and Elton tunnels. With two shafts on the East Delaware tunnel, the driving distance between shafts is 47,660 feet for two headings, and between shafts and portals, the driving distances are 45,450 feet and 38,750 feet, also for two headings each, while headings were about 43,000 feet on the Adams tunnel, about 33,000 feet on the Carlton, and about 24,000 feet on the Elton. Time for completion of the East Delaware tunnel was not a sufficient factor large enough to warrant the spending of additional money for the quicker construction that could be attained with five shafts, as the estimated rate with long headings allowed for completion on or before the time when construction of the Downsville Dam and Pepacton Reservoir could be sufficiently advanced to permit the storage of water. Accordingly, the tunnel is laid out with two construction shafts, one at the Beaverkill and the other at the Willowemoc Rivers. Even at these locations in the river valleys, these two shafts are necessarily deep, the former being 605 feet and the latter 965 feet below the original ground surface at the shaft site.

An additional comprehensive and detailed study was made in connection with the carrying capacity and size of the cross-section of this tunnel, giving due consideration to the economics of the possibility of developing power from waters diverted into the Rondout Reservoir from the Pepacton Reservoir.

The basic requirements for water supply purposes are based on Elevation 1280 for the flow line of the Pepacton Reservoir, with Elevation 1150 for the minimum draft level, and on a tunnel capacity of 600 million gallons daily from the Pepacton portal to Shaft 1, and 750 m.g.d. beyond Shaft 1, with the Pepacton Reservoir 75 per cent depleted, or at an elevation of about 1200. The increased capacity downstream from Shaft 1 provides for future possible developments to the extent of adding 150 million gallons daily to the tunnel flow capacity from there downstream. The tunnel capacity for water supply purposes is, roughly, 50 per cent greater than the estimated safe yield of the watersheds. Studies based on observation in other large tunnels constructed by the City indicated that it was reasonably conservative to use C = 120 in the Hazen Williams formula for friction losses. Hydraulic conditions for these factors indicated that the tunnel should be about 11' - 4" in inside diameter for a length of about 25 miles.

These basic water supply requirements having been set up, a study indicated that as the water system of the City expands, needs to operate at rates above the safe yield should decrease on the more remote reservoirs. Thus a maximum draft of 550 m.g.d. appears in the extreme to be the assumed maximum draft for water supply needs only for the next 25 or 30 years, with much lower maximum drafts probable after that period, and it also appears that such a maximum is not a likely enough probability to be given much thought in considering power development.

A study of depletions of the Pepacton Reservoir based on a 28-year period, October 1913 to October 1941, indicated only one extreme depletion in the period, which was, for 370 m.g.d. (the safe yield draft), an average depletion of 18 per cent, or Elevation 1264 in Pepacton Reservoir; and which was for 400 m.g.d. an average depletion of 28.5 per cent or Elevation 1254. As the maximum design capacity for sure future water supply requirements is for 600 m.g.d. with 75 per cent depletion, it was readily demonstrated that for a considerable time the tunnel will have capacity to furnish water to the City through a power plant without undue depletion of the Pepacton Reservoir level, with drafts in the neighborhood of the safe yield, and with friction losses in the tunnel well reduced because the rates of draft will be well below the design capacity. Also, it was demonstrated that when the time arrives to draw at rates in excess of the safe yield rate, such drafts will be limited in duration and will interfere with power generation only to such extent.

After detailed analyses of cost data, power plant operating costs, and power sales, it was determined that the circular shaped pressure tunnel, 11' - 4" inside diameter, could furnish water at adequate heads for water power development.

As the power development would entail control of drafts from the reservoir at the downstream end of the tunnel, more extensive provisions for water surges in the tunnel are involved, and designs have been made for surge shaft located near the power house. In order to obtain a suitable location of this surge shaft, the tunnel alignment was shifted slightly, entailing a lengthening of the tunnel of about 500 feet over the former locations considered. The power developed will be chiefly firm power, but considerable secondary power will be available for much of the time.

As a result of the above studies of water supply, hydraulics and power development, four contracts were prepared for driving and lining the tunnel, numbered 405, 406, 407 and 408, for the following lengths and headings:

		Overall Length	Headings
Contract	405	20,200 feet	20,200 feet southerly
	406	38,750 feet	18,550 feet northerly 25,000 feet southerly
	407	47,680 feet	22,650 feet northerly 17,700 feet southerly
	408	27,750 feet	27,750 feet northerly

Contract 405 includes, in addition to the tunnel driving and lining, the influent works at Pepacton Reservoir and the northerly portal; 406 includes also Shaft 1; 407 includes also Shaft 2; and 408 includes also the southerly portal and the steel interlining of about 520 feet of tunnel northerly of the portal and the construction of about 195 feet of the 285 feet of concrete lined and covered steel pipe conduit southerly of the portal to the power house and outlet chamber site. The remainder of the concrete lined and covered aqueduct, the power house, other effluent control works and the surge shaft are included under other contracts. Proposals were requested for doing the work required by these contracts in such a manner that bidders could offer prices on any one or more contracts and could offer reductions in case of award of more than one contract, or in case of award of all contracts. Bids were opened on July 19, 1949 and the lowest proposal, taking into account all bids and reductions tendered, was that of Walsh Construction Company and B. Perini & Sons, Inc., in the following amounts:

		Amount of Bid	Reduction if Awarded All 4 Contracts	Net
Contract	405	$ 8,513,505.00	2%	$ 8,343,234.90
	406	14,433,864.50	2%	14,145,187.21
	407	13,560,575.00	2%	13,289,363.50
	408	8,619,175.00	2%	8,446,791.50
Totals		$45,127,119.50		$44,224,577.11

The Board awarded the four contracts to the lowest bidder. The notice to begin work was served on August 9, 1949. On August 1, 1953 driving of the tunnels had been completed, the concrete lining well advanced, and the contract work about 80 per cent completed. Completion of construction within the time allotted (63 months) seems well assured; and, as construction of the Pepacton Reservoir is also well advanced, it looks promising that these tunnels will be ready for diversion of water in 1954, if available and needed.

With the provision for the development of power having been made, control of drafts from the Pepacton Reservoir will be made at the downstream end of the aqueduct instead of the intake end, which would have been preferable for diversions with minimum surges from a standpoint of water supply.

The intake works at the Pepacton end consist of an intake chamber built in rock adjacent to the tunnel portal. This chamber provides two long vertical waterways from Elevation 1178.0 to the flow line, and a lower waterway formed by a tunnel 14 1/2 feet in diameter with invert at Elevation 1143.0 and 203 feet long from the reservoir to the intake works. Each waterway inside the chamber extends from Elevation 1143.0 to the flow line and is 8 1/2 feet wide upstream from the racks and 6 feet wide downstream and contains grooves for racks and openings through solid walls across the waterways and

downstream from the racks for stop shutters. The intake works also include the installation of two Broome type sluice gates for shutting off the tunnel entrance and an access shaft into the tunnel from the surface. When in operation, racks will be placed in the waterways to prevent debris from entering the tunnel. The racks designed consist of vertical flats spaced with 2-inch openings, and cleaning of them at only irregular intervals is considered needed, although grooves are provided for the design and use of a mechanical aid to cleaning in case minor, infrequent hand cleaning operations prove inadequate.

Each waterway leads to cross-wall in which will be installed at vertical intervals the four large stop shutters, 6 feet by 14 feet, at four different levels, which shutters are removable by the use of an overhead crane hoist in the intake works superstructure. The purpose of these shutters is to control the elevations at which water is drawn from the waterways into the tunnel; but, in actual operation, it is doubtful whether much manipulation of these will be needed or desirable.

As the stop shutters can probably be moved only under equalized water pressure conditions, each waterway is further provided with the Broome type sluice gate, 6 feet by 14 feet mechanically operated with its own hoist, located downstream from the shutters as a guard gate to cut off flow into the tunnel from the reservoir in case of shutdown for repairs or inspection, or in case a step shutter should need moving. In a pier between the Broome gates, a 24-inch line serviced by two manually operated 24-inch Dow disc valves in tandem provide for refilling the tunnel after any such shutdown.

This intake structure will be of impressive dimensions, being largely built in a deep V-shaped notch excavated in the rock approach of the portal cut, and the operating floor of the structure being about 160 feet above the invert of the waterway openings and extending along the excavation toward the tunnel for a distance of about 60 feet. It is mainly of heavy reinforced concrete design faced with granite for a depth of 32 feet below the full reservoir level. A superstructure, about 65 feet by 90 feet and about 35 feet high to the underside of roof trusses, which are an additional 15 1/2 feet high, houses the operating facilities at the top, it being designed to be of brick with granite trim.

At Shafts 1 and 2, the permanent works consist only of a cap over the concrete lined shaft for supporting a substantial earthwork cover in which vents for air relief will be located. Each cap will contain removable slabs in case of unanticipated need of access to the tunnel below.

At the downstream end of the tunnel, a steel interlining takes the water pressure when the rock cover lessens near the portal. This interlining consists of a steel plate pipe varying in thickness from 1/2 inch at the upstream and to 1-1/4 inches at the portal and 10-1/2 feet in diameter of welded construction placed inside the tunnel concrete. The steel interlining is protected on the inside from corrosion by a concrete lining 6 inches in thickness, making the net diameter of the aqueduct 9 - 6 . Outside the portal, the aqueduct is designed with the same internal diameter and the same steel pipe construction encased in concrete to form an open-cut conduit to the power house site.

At the southerly end of the aqueduct, the designs provide for two means of operation, one for making releases of water and the generating of power, and the second, for making releases directly without such generation. The latter operation requires provisions for the dissipation of energy; and, as the result of considerable study, the design of a stilling basin seemed the best solution.

Thus, founded on rock, the outlet works consist of two parts: the power house containing 22,500 k_V. generating equipment and appurtenances, and an outlet chamber, a stilling basin, tailrace, overflow weir and discharge channel. The lowest bidder, Booth & Flinn Company, was awarded the contract for constructing both parts of these outlet works at a bid price of $1,608,570 which price did not include the superstructure nor furnishing the waterwheel, generator, large valves and other equipment. Notice to begin work was served May 19, 1952 and the time of completion set at 33 months. Because of the nearness to completion of construction work on the Pepacton Reservoir and the East Delaware Tunnel, efforts are being strenuously made to effect completion to the extent that the works will be ready for generation of power by January 1, 1955, with possible by-pass releases before that time. Under an agreement between the City of New York and the Rockland Light and Power Company, the City is being reimbursed for construction on that portion of the work. Also under a separate construction contract, that power company is building the surge shaft connecting to the tunnel at a location about 1200 feet upstream from the plant.

As an excellent paper describing the features of this power plant was presented in November 1950 before the New England Water Works Association, and is printed in the Journal of that association, by George R. Rich, partner of Chas. T. Main, Inc., consulting engineer for the power company, no further details of the plant set-up will be repeated here. In that paper is also described the terms of the agreement between the City and the power company in which damages suffered by the company by the construction of the water supply facilities are compensated for by granting to the company rights to generate power up to a restricted amount for the next 50 years. Any excess generated power will be paid for by the company to the City and the plant becomes the property of the City at the end of the stipulated period.

The by-pass provisions, owned and operated by the City for such releases as are required at times when power is not or cannot be generated, consist mainly of four lines of steel plate pipe construction connected to the steel pipe conduit just upstream from the power house. Three of these lines are 64 inches in finished inside diameter and the fourth is 48 inches. All four lines lead to an outlet chamber which is built underground and which will be covered with removable reinforced concrete slabs. This chamber houses the release control valves which consist of two 48-inch cone valves in tandem on each of the three larger lines and of two 36-inch cone valves in tandem on the smaller line. The lines extend through the outlet chamber to a stilling chamber and the energy is dissipated there through orifices 23 inches in diameter on each of the three larger lines, and 17-1/4 inches in diameter on the smaller line. The stilling chamber will be maintained full of water and such dissipation of energy takes place submerged. The stilling chamber is also built underground and consists mainly of a chamber 87 feet by 62-1/2 feet by 25 feet high, with access through a large vented rectangular access structure about 27 feet by 56 feet, and projecting about 12 feet above the finished grading.

Both the stilling chamber and the power plant are connected to a common tailrace about 89 feet by 50 feet at the downstream end of which is an overflow concrete weir, 89 feet long by 16 feet wide and 14 feet high, to be built to maintain a fairly constant level of water in the tailrace. Downstream from this weir will be a paved discharge channel for directing the flow of water into Rondout Reservoir.

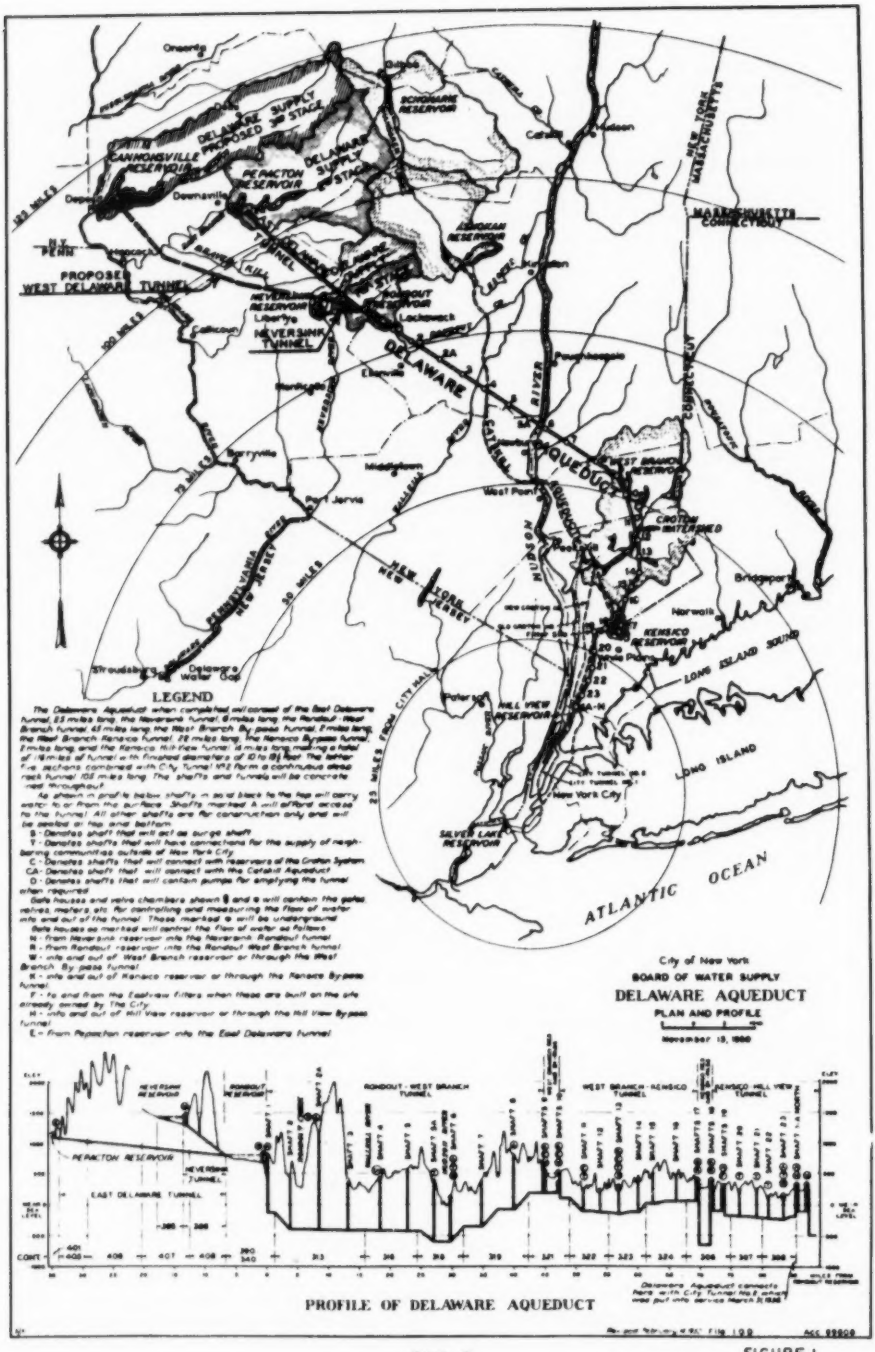
The surge shaft being built by the power company consists essentially of a shaft sunk mainly in rock about 400 feet deep and about 40 feet in diameter

for the upper half, and 11 - 4 in diameter for the lower half, after lining. It contains a 10-foot outside diameter steel riser pipe which will extend about 100 feet above the original surface of the ground to Elevation 1325± in a 40-foot diameter steel shell anchored into the rock and protected on the outside with wood lagging and will care for surges up to and over 33 feet above the Pepacton Reservoir flow line level. This construction was effected by contracts between the Rockland Light and Power Company and the Foundation Company and Walsh Construction Company & B. Perini & Sons, Inc.

Acknowledgement

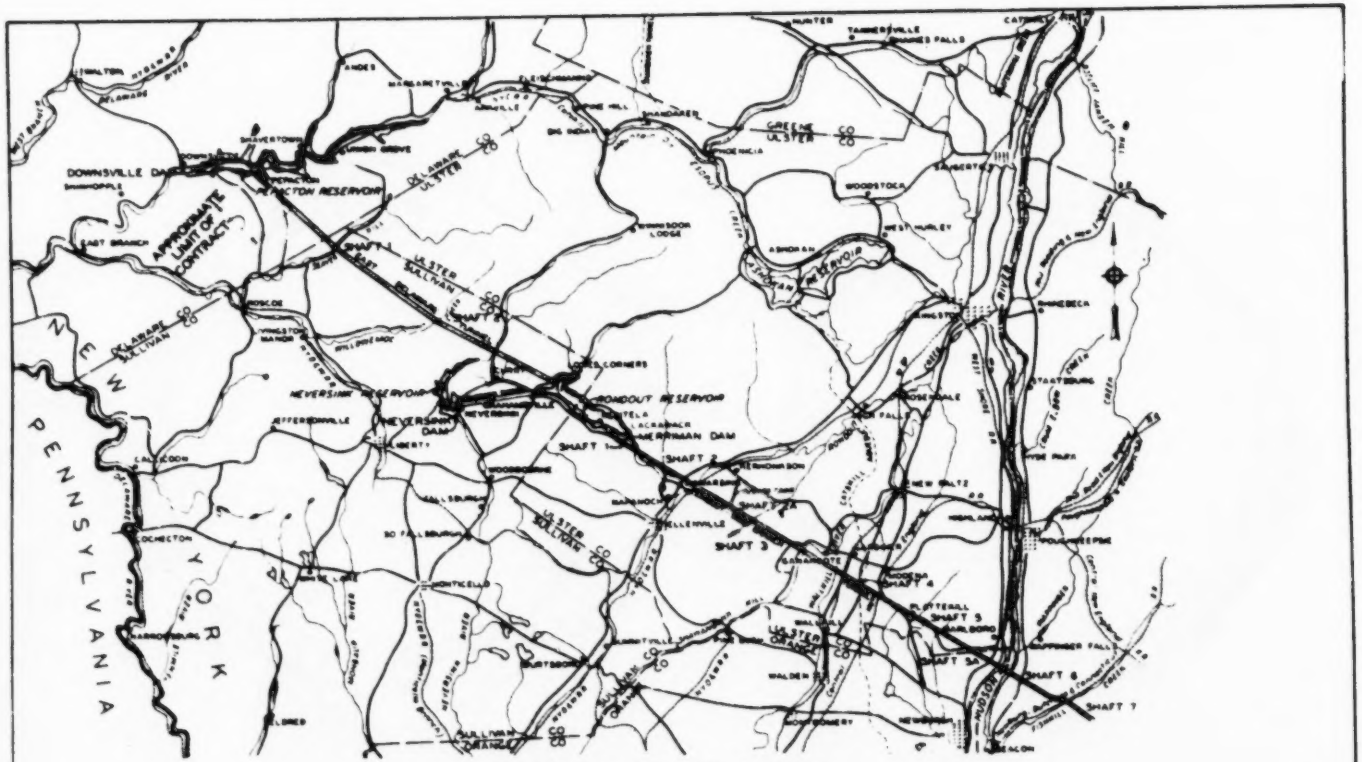
The activities of the Board of Water Supply are directed by three Commissioners: Irving V. A. Huie, President, Rufus E. McGahen and Edward C. Maguire. John M. Fitzgerald, deceased since April 1, 1952, was formerly Chief Engineer, and his successor, Karl R. Kennison, is now Chief Engineer. The writer is Deputy Chief Engineer in charge of design, succeeding Victor C. Brownson, now retired. Torris Eide, Department Engineer at headquarters' office on design, is responsible in major degree for supervision of the many design features studied in connection with this tunnel project and with the supervision of the preparation of contract specifications and drawings for the construction of it, and the writer is indebted to him for material assistance in the preparation of this paper, as well as to other members of the engineering staff of the Board for other aid.

Chas. T. Main, Inc. of Boston were the designing engineers for the Rockland Light and Power Company on the power station, surge tank and appurtenant work.


LEGEND
The Delaware Aqueduct when completed will consist of the East Delaware tunnel, 85 miles long; the Neversink tunnel, 6 miles long; the Rondout - West Branch tunnel, 44 miles long; the West Branch By-pass tunnel, 2 miles long; the West Branch-Kensico tunnel, 28 miles long; the Kensico By-pass tunnel, 2 miles long; and the Kensico-Hill View tunnel, 16 miles long; providing a total of 183 miles of tunnel or its finished diameters of 10 to 15 feet. The latter five sections combined with City Tunnel No. 1 form a continuous aqueduct rock tunnel 105 miles long. The shafts and tunnels will be concrete lined throughout.
As shown in profile below, shafts in solid black to the top will carry water to or from the surface. Shafts marked A will afford access to the tunnel. All other shafts are for construction only and will be sealed at top and bottom.
B - Denotes shaft that will act as surge shaft.
T - Denotes shafts that will have connections for the supply of neighboring communities outside of New York City.
C - Denotes shafts that will connect with reservoirs of the Croton System.
CA - Denotes shaft that will connect with the Catskill Aqueduct.
D - Denotes shafts that will contain pumps for emptying the tunnel when required.
Gate houses and valve chambers shown G and V will contain the gates, valves, meters, etc. for controlling and measuring the flow of water into and out of the tunnel. Those marked V will be underground.
Gate houses as marked will control the flow of water as follows:
N - from Neversink reservoir into the Neversink-Rondout tunnel.
R - from Rondout reservoir into the Rondout West Branch tunnel.
W - into and out of West Branch reservoir or through the West Branch By-pass tunnel.
K - into and out of Kensico reservoir or through the Kensico By-pass tunnel.
F - to and from the Eastview filters when these are built on the site already owned by The City.
H - into and out of Hill View reservoir or through the Hill View By-pass tunnel.
E - From Pepacton reservoir into the East Delaware tunnel.
City of New York
BOARD OF WATER SUPPLY
DELAWARE AQUEDUCT
PLAN AND PROFILE
November 19, 1938
PROFILE OF DELAWARE AQUEDUCT

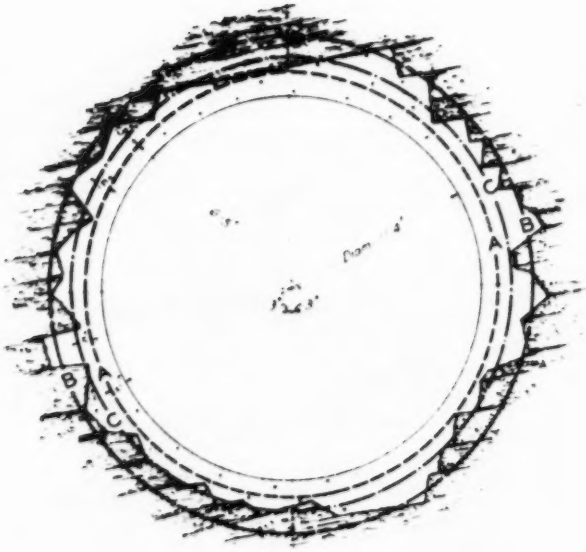
313-8

FIGURE 1



EAST DELAWARE TUNNEL
LOCALITY MAP

FIGURE 2



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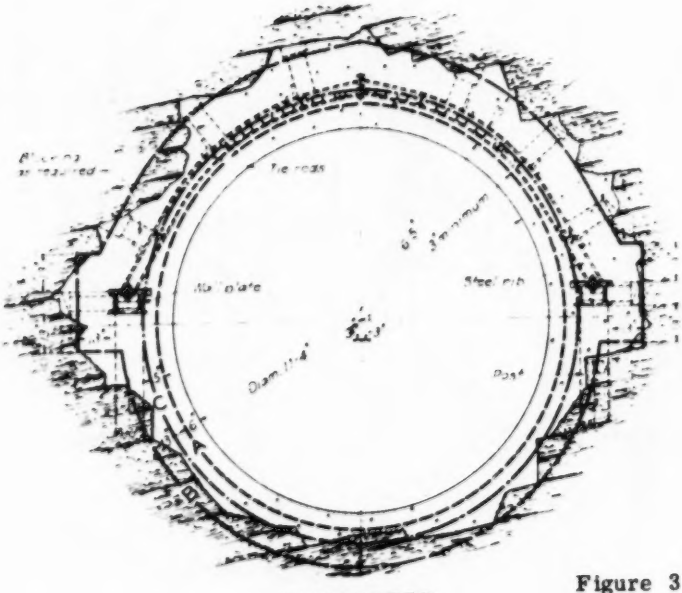


SUPPORTED

Figure 3

TYPICAL TUNNEL SECTIONS

313-10

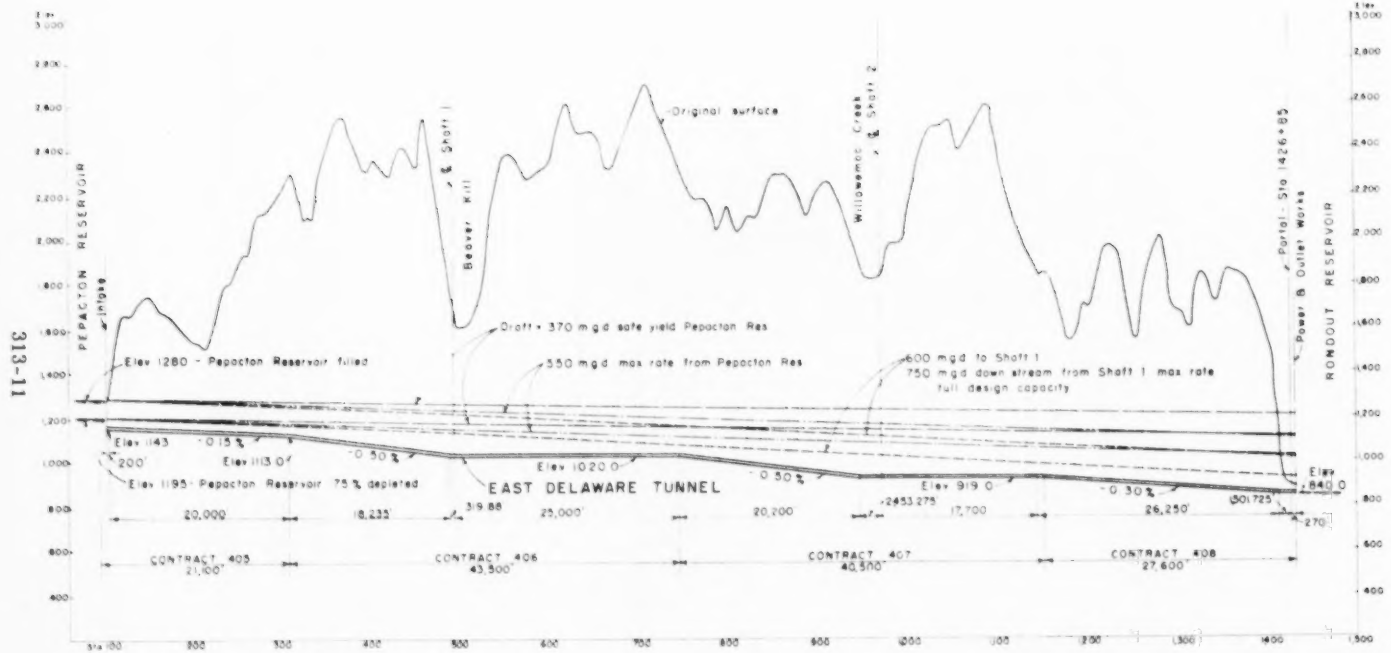
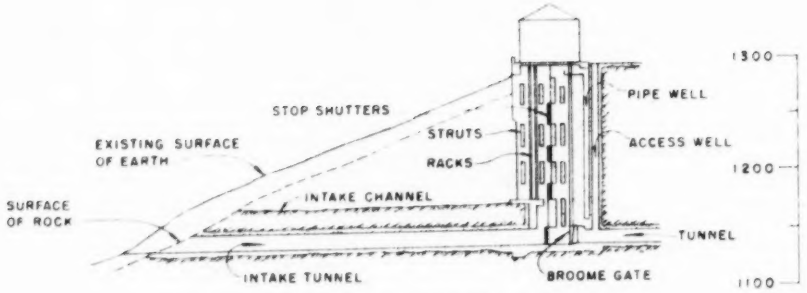


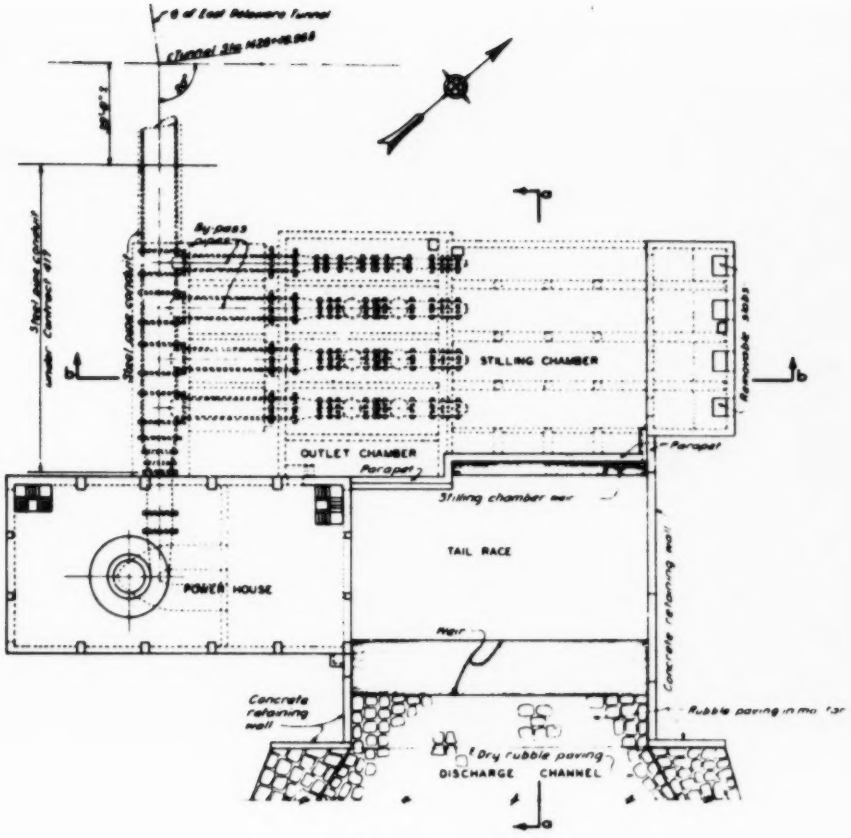
Figure 4

TUNNEL PROFILE - CONTRACT LIMITS - HYDRAULIC GRADES

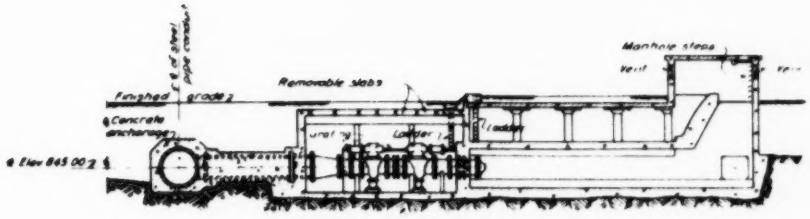


PROFILE OF INTAKE CHAMBER

FIGURE 5



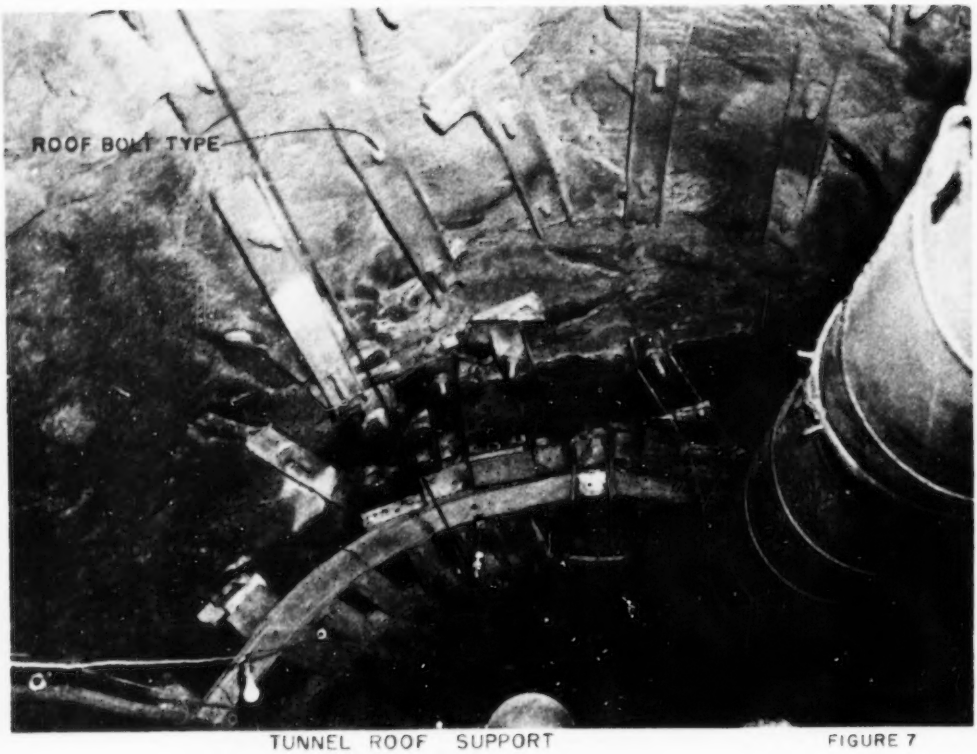
PLAN



SECTION b-b

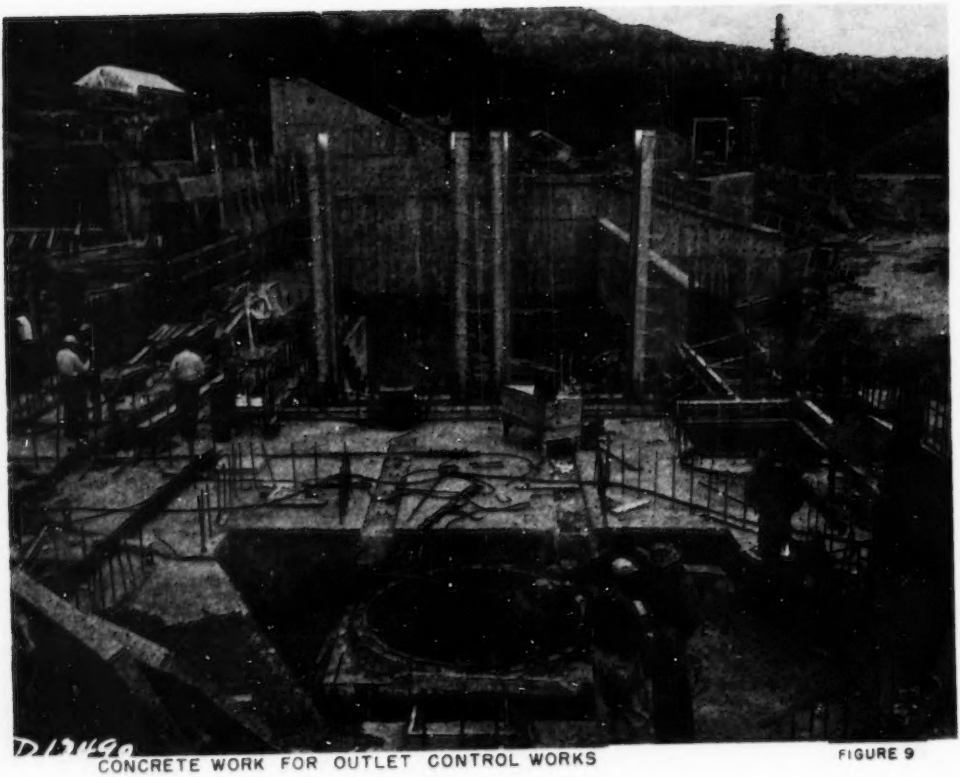
OUTLET CONTROL WORKS

Figure 6



TUNNEL ROOF SUPPORT FIGURE 7

EXCAVATION FOR INTAKE CHAMBER FIGURE 8



CONCRETE WORK FOR OUTLET CONTROL WORKS

FIGURE 9

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